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# THE CHOICE OF CROPS FOR ALKALI LAND

THOMAS H. KEARNEY

Physiologist in Charge of Alkali and Drought Resistant  
Plant Investigations



FARMERS' BULLETIN 446

UNITED STATES DEPARTMENT OF AGRICULTURE

Contribution from the Bureau of Plant Industry

WM. A. TAYLOR, Chief

Washington, D. C.

Issued May, 1911; revised June, 1920

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**I**T HAS BEEN ESTIMATED that the productive-  
ness of  $1\frac{1}{2}$  million acres of irrigated land in the  
western United States is seriously impaired by the  
presence of alkali salts. Whenever possible, such  
land should be reclaimed by underdrainage and  
flooding, but reclamation of much of this area is not  
immediately practicable. Pending reclamation it is  
important to know what crops are most likely to  
succeed on land of this character.

As a rule, forage crops are more likely to be profit-  
able on alkali land than plants which are grown for  
their fruits or seeds. Certain meadow and pasture  
grasses, sorghum, barley, and rye, as hay crops, sweet  
clover, and rape give fairly satisfactory results where  
the salt content of the soil is not excessive. Alfalfa  
will withstand a moderate quantity of alkali if a  
stand can be obtained. Sugar-beet plants are very  
tolerant, but the size and quality of the roots are in-  
ferior when much alkali is present. Cotton is fairly  
resistant, but in strong alkali soils the fiber suffers  
in length and strength.

In all cases a stand is much more likely to be ob-  
tained if the seed is put in as soon as possible after  
a rain or a heavy irrigation, which washes much of  
the salt out of the surface soil and thus creates better  
conditions for germination and seedling growth.

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## PURPOSE OF THE BULLETIN.

One of the most serious obstacles to agriculture in the arid portion of the United States is the frequent presence in the soil of alkali—an excess of readily soluble salts. Irrigated land that has a high water table is most likely to suffer from this cause.

The history of agricultural development in the West contains numerous instances of irrigation projects that had a promising beginning in localities where land values have subsequently been much impaired by the rise of alkali. It has been estimated that one-tenth of the irrigated land in the western United States, or approximately 1,500,000 acres, contains an injurious quantity of alkali salts. Some of the most valuable land in that part of the country, adapted at the outset to the best-paying crops and situated most advantageously with respect to towns and transportation lines, has become practically useless through the operation of this cause.

The remedy unquestionably is to get rid of the excess of salts wherever possible by flooding and drainage. But it often happens that there are obstacles in the way of reclaiming alkali land. The individual farmer may not be able to secure an outlet for his waste water until a cooperative drainage system has been established in his neighborhood. Climatic conditions or the distance from markets may prevent the growing of sufficiently profitable crops to warrant the cost of reclamation. Even where reclamation is feasible the process often requires several years, and meantime both the land and the farmer's pocketbook will benefit if some crop is put in at the earliest stage when a stand can be secured. Prolonged flooding of



land which previously contained a large quantity of alkali salts is apt to impair the texture of the soil, especially if a heavy one, causing it to become puddled. This will be avoided to some extent if crops are grown during the progress of reclamation.

The object of this bulletin is to bring to the attention of owners of alkali land the crop plants which are most likely to give satisfactory results. It can not be too emphatically stated that crop production on such soils is at best precarious. For this reason and because the alkali resistance of plants depends upon many varying conditions, it is impossible to offer more than suggestions as to what crops are best worth trying.<sup>1</sup>

### CHEMICAL NATURE OF ALKALI.

Alkali consists of various chemical compounds (salts) which are often present in western soils in sufficient quantity to hinder or prevent the growth of plants. Most of these salts are familiar to everyone from their medicinal or household uses. The most common of these substances are Glauber's salt (sodium sulphate), table salt (sodium chlorid), and baking soda (sodium bicarbonate). The so-called "black alkali" is sal soda, or washing soda (sodium carbonate). Epsom salts (magnesium sulphate) is also an important ingredient of alkali in certain localities. All of these salts readily dissolve in water. Less soluble compounds that often occur in alkali soils are the carbonates of lime and magnesia and the sulphate of lime (gypsum, or land plaster).

It seldom, if ever, happens that only one kind of salt is present. Alkali is almost always a mixture of several salts, the kind and the proportions in which they are mixed differing in different localities. But often some one salt forms the bulk of the alkali, and hence we

<sup>1</sup> The scope of this paper does not include methods of reclamation for alkali land. Problems of soil management are discussed only incidentally in connection with the different crops. For information upon these subjects and upon the chemistry and physics of alkali, the reader is referred to other publications of the Department of Agriculture and of the agricultural experiment stations of the Western States. In Bulletin 35 of the Bureau of Soils, entitled "Alkali Soils of the United States," by Clarence W. Dorsey, brief summaries are given of publications issued prior to 1906, in addition to a general discussion by the author. In Prof. Hilgard's work on "Soils," published in 1906, the subject of alkali soils is treated at considerable length (pp. 422-484). Methods for the reclamation of alkali land by drainage are described in Bulletin 21, Bureau of Soils, entitled "Reclamation of Alkali Land in Egypt," by Thomas H. Means; in Bulletin 34, Bureau of Soils, entitled "Reclamation of Alkali Soils," by Clarence W. Dorsey; in *Farmers' Bulletin* 371, entitled "Drainage of Irrigated Lands," by Charles F. Brown; in Bulletin 217, Office of Experiment Stations, entitled "Drainage of Irrigated Lands in the San Joaquin Valley, California," by Samuel Fortier and Victor M. Cone; in Bulletin 111, Utah Experiment Station, entitled "The Reclamation of Seeped and Alkali Lands," by C. F. Brown and R. A. Hart; and in *Farmers' Bulletin* 805, entitled "The Drainage of Irrigated Farms," by R. A. Hart. The alkali content of and limits for the safe use of irrigating waters are discussed in Water Supply Paper 274 of the U. S. Geological Survey, entitled "Some Stream Waters of the Western United States," by Herman Stabler, and in Bulletin 169 of the Utah Experiment Station, entitled "The Use of Alkali Water for Irrigation," by F. S. Harris and N. I. Butt.



can speak of "sulphate alkali" where Glauber's salt and other sulphates are the chief ingredients, of "chlorid alkali" where common salt is the most abundant, and of "black alkali" where a considerable quantity of sodium carbonate occurs.

In many irrigated districts, especially in those situated east of the Rocky Mountains, Glauber's salt (sodium sulphate) forms the bulk of the alkali. But in some of the largest areas of alkali land in the United States common salt (sodium chlorid) is the most abundant compound present. Considerable quantities of sodium bicarbonate are often associated with both the sulphate and the chlorid types. The areas where black alkali (sodium carbonate) predominates are much more restricted.

### REASONS FOR THE APPEARANCE OF ALKALI.

The characteristic alkali salts are readily soluble in water and when dissolved move upward or downward as the soil moisture moves. Conditions that favor evaporation from the surface of the soil favor the accumulation of alkali at or near the surface, while a rainfall or an irrigation carries the salts downward. Alkali is rarely found in the United States east of the ninety-fifth meridian, not because eastern soils are essentially different from western soils, but because the heavier rainfall of that part of the country leaches out most of the soluble matter as fast as it is formed in the soil and carries it away in the country drainage. In many parts of the Western States the rainfall is too scanty to effect this leaching and the salts remain in the soil, often at or near the surface.

In land that has never been irrigated, the presence of alkali is seldom apparent except in low spots where water accumulates during rains and in valley bottoms where the ground-water table is close to the surface. Yet after irrigation has begun alkali often appears at the surface of land which previously seemed to be quite free from it. In such case the salts may have been present originally in lower depths of the soil, and it is the raising of the water table resulting from continued irrigation which has brought them into connection with the moisture of the upper layers. Evaporation will then gradually lift the alkali to the surface and if long continued will cause the formation of the characteristic white crust of salts. Or it may be the application of water to adjoining higher lands which has filled the lower-lying areas with an excess of salts, the surplus water having drained off into the valley bottoms and carried there with it a great part of the salts originally contained in the upland soils from which it came. Continued irrigation with river or well water having a high salt content is another cause of land becoming impaired through the accumulation of alkali.



In districts where alkali soils occur, the fields are apt to have a spotted appearance, due to the accumulation of the salts in more or less sharply defined areas, outside of which there may not be a sufficient quantity of alkali to interfere with the growth of crops. The bare spots may be only a few feet in diameter, or they may occupy several acres. This local accumulation of the alkali is usually due to differences in level, the salts accompanying the water to the low spots. Differences in soil texture also play a part, the water and the dissolved salts accumulating where the soil is least pervious and the drainage is poorest.

### EFFECT OF ALKALI UPON PLANT GROWTH.

The harmfulness of alkali depends not only upon the quantity and the kind of salts, but also upon the amount of moisture the soil contains. The soil moisture is controlled by climatic conditions (rainfall, evaporation, etc.), by the frequency and heaviness of irrigation, by the texture of the soil, and by the conditions for drainage. Furthermore, the distribution of the salts in different depths of the soil, in relation to the character of the root system of the plant, must be taken into consideration.

### COMPARATIVE HARMFULNESS OF DIFFERENT KINDS OF ALKALI.

The sulphate, chlorid, and bicarbonate, collectively known as "white alkali," are much more abundant in most localities than the carbonate, or "black alkali."

Black alkali, which can usually be recognized by the dark color it imparts to the surface soil and to standing water,<sup>1</sup> is far more injurious to plants than the white-alkali salts. It is a strong corrosive, causing the decay of plant tissues. Trees growing in black-alkali land are sometimes completely girdled at the crown through the corrosive action of the sodium carbonate. This salt also has a bad effect upon the texture of heavy soils, causing them to become puddled.

Where the soil contains considerable black alkali it is useless to attempt to grow crops until this condition is remedied. If gypsum, or land plaster, can be obtained at a reasonable cost, and the value of the land warrants its use, the black alkali can often be converted to less harmful salts by successive applications of this fertilizer. The effect of the gypsum is to neutralize chemically the black alkali. This results in loosening the soil, making it easier for water to penetrate, and aiding the washing down of the other salts. The presence of more than one-tenth of 1 per cent of sodium carbonate is injurious

<sup>1</sup> This indication is sometimes misleading, however, for the dark color may be produced by less harmful salts, and the carbonates themselves may not produce the stain if the soil contains but little humus.



to the growth of practically all crop plants. For most species one-twentieth of 1 per cent (0.05 per cent) of this extremely noxious salt is too much for good crop production.

The white-alkali salts are not corrosive, but when freely taken up into the cells of the plant they cause serious disturbances in its nutrition. If present in the soil in sufficient quantity, these salts also hinder the absorption of water by the plant roots, so that even when the soil is quite wet the plants may actually be suffering from lack of water. This is doubtless one of the chief reasons why seeds germinate more slowly where alkali is present.

The chlorid type of white alkali is somewhat more harmful to most crop plants than the sulphate type. The bicarbonates as such do not appear to be very injurious, but there is always danger where bicarbonates are present that black alkali will be formed by chemical action.

#### QUANTITY OF ALKALI PRESENT.

The harmfulness of alkali depends upon the quantity as well as the kind of salts present. The alkali content of a soil is usually expressed in percentages of its total dry weight. Thus, if 100 pounds of dry soil contains 1 pound of salts that are easily soluble in water, its alkali content is said to be 1 per cent. As a rule, if the soil contains more than one-half of 1 per cent of white-alkali salts, only decidedly resistant plants can be grown.

The kind of salts present in a given alkali soil can be determined only by chemical analysis, but in the absence of black alkali it will usually suffice for practical purposes to ascertain merely the total quantity of easily soluble material. This is most readily done by determining the electrical resistance of the soil when saturated with water. A convenient instrument for this purpose is the electrical bridge, described in Bulletin 61, Bureau of Soils, United States Department of Agriculture (1910). From the electrical resistance the percentage of salts to dry weight of the soil can be calculated.

#### SOIL MOISTURE.

Even if the total quantity of alkali in a given volume of soil remains the same, the strength of the solution which surrounds the roots and from which they must extract the water and plant-food salts needed for growth will vary with every change in the soil moisture. For example, if 20 pounds of water be added to 100 pounds of air-dry soil containing 1 pound of alkali salts, the bulk of the salts will be dissolved in the 20 pounds of water and the concentration of the soil solution will be approximately 1 part in 20, or 5 per cent. If an additional 20 pounds of water is added without increasing the quantity of salts present, the concentration of the soil solution will be reduced to 2.5 per cent. If the soil is now allowed to



dry out until it contains only 10 pounds of water, a 10 per cent solution will result, supposing the moisture and the salts dissolved in it to remain evenly distributed throughout the soil.

It is therefore evident that a mere statement of the percentage of alkali present in a soil tells us little about how plants will be affected. It is the strength of the solution around their roots which concerns them. Plants which could make a thrifty growth in a soil containing a given percentage of alkali, provided that irrigation were so managed as to maintain a moisture content of 30 per cent, might suffer severely if the same soil, without change in the alkali content, were allowed to dry out until only 20 per cent of moisture remained.

Similarly, some plants which can endure 1 per cent of alkali if present in a heavy soil would quickly perish in a sandy soil containing the same quantity and the same kind of salts, the reason being that the heavier soil can hold more water. If a clay loam and a very sandy soil both hold 1 per cent by dry weight of alkali and are both saturated with water, the soil solution in the former may be only one-fourth as concentrated as in the latter.

The moisture content of the soil is, of course, subject to the control of climatic factors, especially precipitation and evaporation. In regions of winter rainfall like California a winter crop might succeed better in alkali land of a given concentration than a summer crop that is actually more resistant. During the rainy season the soil solution is frequently diluted by the water that falls upon the land, and evaporation is relatively slight. Hence, the surface soil is likely to remain nearly free from salts during the entire period when the crop is growing. On the other hand, the growth of the summer crop takes place during the period when evaporation is most rapid and is tending to accumulate the salts near the surface of the soil. At the same time the dry, hot weather stimulates transpiration or loss of water from the plants themselves just when the increased concentration of the soil solution makes it hardest for their roots to take up water. An irrigated summer crop is subject to great fluctuations in this respect, the soil solution being very dilute immediately after an application of water, but becoming daily more concentrated through the action of evaporation.

Methods of irrigation have a great deal to do with the movement of the soil moisture and consequently with the distribution of the alkali. If the land is level, a heavy flooding will cause the water to move downward over the whole surface of the field, carrying the salts with it. On the other hand, furrow irrigation carries down whatever alkali is present at the bottoms of the furrows, but sub-irrigates the soil between them, causing an accumulation of salts at the summit of the ridges. This action will be intensified if the irrigation water itself carries considerable alkali.



**STAGE OF GROWTH OF THE PLANT AND CHARACTER OF ITS ROOT SYSTEM.**

Another important consideration in determining the effect of a given quantity of alkali is its vertical position in the soil in relation to the depth reached by the plant roots. A comparatively small quantity of alkali, if mostly accumulated near the surface, will prevent getting a stand of many crops which can be successfully started if a heavy rain or irrigation has occurred just before planting is done. The effect of the large quantity of water thus added is, of course, to carry much of the salt into the lower depth of the soil, leaving a comparatively dilute solution in the portion occupied by the germinating seeds and the roots of the young seedlings. Then by the time evaporation has produced a new accumulation of salts at the surface, the feeding roots of the plants may have penetrated deep enough to be out of reach of the concentrated solution that has once more formed in the topsoil. Alfalfa serves to illustrate this relation, since the seedlings develop a taproot that penetrates very rapidly into the soil. If the salts have been washed out of the surface 6 inches just previous to seeding, a stand may be obtained and the plants may escape injury, even if an alkali crust is subsequently formed. This doubtless explains the fact that flourishing fields of alfalfa several years old are occasionally seen where the quantity of salts now present in the topsoil would make it impossible to get a stand, the alkali having evidently risen since the seeding was done.

On the other hand, most of the alkali may be located in a deeper portion of the soil, a condition which is especially unfavorable to deep-rooted plants, such as alfalfa, cotton, and trees. In irrigated land this condition is nearly always associated with a high water table, which is itself unfavorable to deep-rooted plants, but deep-lying deposits of salts may occur in unirrigated soils or in irrigated soils having a low water table. Such deposits are often associated with a clay subsoil or a lime hardpan. In these cases comparatively shallow-rooted plants like the cereals and the meadow grasses can often be successfully grown where deep-rooted plants would soon die.

**GERMINATION.**

It is evident from the foregoing that on alkali land, no matter what crop is grown, it is always advisable to put in the seed as soon as possible after a heavy rainfall or irrigation. This is especially important with small seeds, like those of the meadow grasses and of alfalfa. If even with this precaution the topsoil still holds a fairly strong salt solution, there is good reason to believe that large-seeded plants can often be started more easily than small-seeded plants of the same family. The vigorous early growth that is per-



mitted by a large seed stored with abundant reserve food materials and the resulting rapid penetration of the roots are probably the deciding factors in such cases.

#### NATURE OF THE PRODUCT FOR WHICH THE CROP IS GROWN.

Because a plant can grow in the presence of a given quantity and kind of alkali it does not necessarily follow that it will be a successful crop under such conditions. The effect upon the product for which the crop is grown must also be considered. Wheat plants can make a good growth in the presence of a quantity of alkali that will not permit the formation of well-filled heads of plump grain. Various kinds of fruit trees can endure a concentration of alkali that seriously injures the texture, sweetness, flavor, and keeping quality of the fruit. The burning quality of tobacco, the length and fineness of cotton fiber, and the purity coefficient of sugar cane and beets may be impaired by a quantity of salts that is too small to interfere seriously with the growth of the plants. On the other hand, in the case of such forage plants as are grown chiefly for a large production of stems and leaves, the actual alkali resistance of the plants as shown by their vegetative growth measures the possibility of crop production on alkali land.

### CROP PLANTS ADAPTED TO DIFFERENT GRADES OF ALKALI.

#### GRADES OF ALKALI DISTINGUISHED.

The following grades of alkali may be distinguished, the grades being based upon the percentage of soluble salts by weight in a given depth of the soil. In referring to the different grades when discussing the alkali resistance of any particular crop plant, it is assumed that the depth of soil is that ordinarily occupied by the roots of the plant in question.

TABLE I.—*Classification of the different grades of alkali.*

Designation of the grade. <sup>1</sup>	Proportion of soluble salts to total dry weight of the depth of soil reached by the roots.
	<i>Per cent.</i>
Excessive.....	More than 1.5
Very strong.....	1.0-1.5
Strong.....	.8-1.0
Medium strong.....	.6- .8
Medium.....	.4- .6
Weak.....	.1- .4
Negligible.....	Less than .1

<sup>1</sup> These terms are used in order to avoid a constant repetition of figures of percentages in discussing the alkali relations of crop plants.



As shown on a preceding page, it is the concentration of the soil solution within reach of the roots and not the mere quantity of salts present which actually determines the effect of alkali upon plant growth. But as the soil moisture and hence the strength of the solution are extremely variable, alkali land can be classified only on the basis of percentages of the salts to the dry weight of the soil. In using the above classification in discussing the resistance of plants, it is assumed that the soil contains a degree of moisture favorable for the growth of the crop in question; also, that the soil is not extremely sandy, for sandy soils hold much less water than loams or clays, and hence a given percentage of alkali produces a more concentrated solution in very light soils.

#### CROP PLANTS ADAPTED TO THE DIFFERENT GRADES.

The limits given are those for crop production and take into consideration such matters as quality of the grain in cereals, of the fiber in cotton, and of sugar content in sugar beets. The term "good crop" implies an approach to the normal production in alkali-free soils, while "fair crop" implies a product giving a reasonable return on the investment, the relatively low value of the land being considered. The limits as given apply to the maturing crop. For germination and growth during the seedling stage the limits will in many cases be considerably lower.

It should be understood that any classification of crops on the basis of their alkali resistance can be applicable only in a very general way, owing to the varying nature of the conditions (discussed in the preceding sections of this bulletin) which determine resistance in any particular locality or soil. The classification applies most closely where the alkali is of the sulphate type. In localities where common salt (sodium chlorid) forms the bulk of the alkali it will be found that most of the crop plants mentioned succeed best at the lower limits of the respective grades. If an appreciable quantity of black alkali is present, the classification will not hold good at all.

In spite of these limitations, it is believed that the following grouping will be useful as a guide to the selection of crops for testing in alkali soils, since the comparative tolerance of the different plants is sufficiently indicated. Further details regarding the alkali resistance of each crop are given under "Alkali resistance of the different crop plants" (pp. 17 to 29).

**Excessive alkali.**—Only a very few useful plants can be depended upon to grow where more than 1.5 per cent of the dry weight of the soil consists of alkali salts. Chief among these are the native and foreign saltbushes and related plants of the goosefoot family (*Chenopodiaceæ*), which are of some value as forage. Certain native



grasses, notably salt-grass (*Distichlis spicata*), which affords pasturage of rather inferior quality, can endure more than 1.5 per cent of white alkali. Sugar-beet plants can grow in the presence of as much as 2.5 per cent, but the roots produced are small, the sugar content low, and the ash content of the juice too high. Among fruit trees the date palm is the only species that is at all likely to succeed.

**Very strong alkali.**—Where there is not more than 1.5 per cent of salts in the soil, if other conditions are exceptionally favorable sugar beets may give a fair crop, although they are not to be recommended for soils containing this quantity of alkali. The date palm is still the only fruit tree which can be expected to yield fruit of good quality. Pomegranate bushes will grow, but will probably not yield edible fruit.

**Strong alkali.**—Under otherwise favorable conditions the following plants may be expected to give fair crops in soils holding not more than 1 per cent of salts: Sugar beets, western wheat-grass, awnless brome-grass, and tall meadow oat-grass.

**Medium-strong alkali.**—In soils that contain not more than 0.8 per cent of salts, good crops may be grown of the following meadow and pasture grasses: Western wheat-grass, brome-grass, tall meadow oat-grass, and, when once established, of Italian ray-grass (or rye-grass), meadow fescue, and slender wheat-grass; also, of sugar beets and common or foxtail millet. Fair crops of rape, kale, sorghum, and barley hay may be grown.

**Medium alkali.**—The following plants should give good crops in soils containing not more than 0.6 per cent of salts: Sorghum, common or foxtail millet, rape, kale, redtop, timothy, orchard grass, barley, rye, cotton, and asparagus. Fair crops are possible of milo, kafir, proso millet, wheat, oats, emmer, alfalfa, field peas, sweet clover, vetches, and flax. Among orchard crops, pears and possibly figs may be grown if other conditions are favorable.

**Weak alkali.**—Where the soil contains not more than 0.4 per cent of salts, good crops may be expected of nearly all forage plants and of the cereals except corn. Among truck crops, the beet, cabbage, cauliflower, celery, eggplant, kale, spinach, Irish potato, sweet potato, tomato, and watermelon are the most likely to succeed. Grapes of the European type (*Vinifera*) can be produced if other conditions are favorable.

**Negligible alkali.**—Practically all field-crop plants can be expected to produce profitably in the presence of less than 0.1 per cent of white alkali if other conditions are favorable. Few of the truck and orchard crops are likely to suffer.

As previously stated, however, the limits for all of these crops will be lower if the alkali is largely accumulated near the surface of the



soil, especially at the time of seeding. Moreover, less alkali can be endured if the soil is very sandy or if an appreciable quantity of black alkali is present. The existence of other unfavorable conditions, such as a deficiency of necessary plant-food elements in the soil, diseases of various kinds, and in the case of trees and other deep-rooted plants a high water table, may lower the limits of tolerance below what would be the case where alkali is the only injurious factor.

In Table II lists are given of the crop plants which are most likely to succeed on land containing different grades of alkali. Only such plants as may be expected to give at least a fair crop in the absence of the unfavorable conditions mentioned in the preceding paragraph are included under each grade.

TABLE II.—Crop plants which are most likely to succeed in the presence of different grades of alkali.

Weak alkali (0.1 to 0.4 per cent).	Medium alkali (0.4 to 0.6 per cent).	Medium strong alkali (0.6 to 0.8 per cent).	Strong alkali (0.8 to 1 per cent).	Sugar beets. Western wheat-grass. Awnless brome-grass. Tall meadow oat- grass.
				Meadow fescue. Italian ray-grass. Slender wheat-grass. Foxtail millet. Rape. Kale. Sorgo. Barley (hay crop).
				Redtop. Timothy. Orchard grass. Cotton. Asparagus. Wheat (hay crop). Oats (hay crop). Barley (grain crop). Rye (grain crop). Sweet clover.
				Wheat (grain crop). Emmer (grain crop). Oats (grain crop). Kafir. Milo. Proso millet. Alfalfa. Field peas. Vetches. Horse bean.



## CONSIDERATIONS GOVERNING THE CHOICE OF CROPS FOR ALKALI LAND.

The owner of alkali land who wishes to select crop plants for trial from the preceding list should first make a careful study of his situation, finding out all he can about the quantity of alkali present in his land, the height of the water table, and the opportunities for drainage and for washing out the salts, at least from the surface soil. He should also take into consideration the climate of his region, which necessarily limits the number of available crops, and the local marketing conditions, which determine what crops can be profitably disposed of.

If it should prove practicable to reclaim the land by flooding and drainage, the question will arise, What crops can be grown to best advantage during the progress of the work? If the soil is in poor physical condition or is deficient in humus or nitrogen, alkali-resistant green-manure crops should be tried whether or not the land is to be reclaimed by drainage. If immediate reclamation is not feasible, crops and tillage methods should be preferred which help to check evaporation and prevent the further accumulation of salts in the topsoil. If the water table is high and drainage is impracticable, shallow-rooted plants must be selected.

The following paragraphs contain suggestions as to the crop plants best adapted to these different conditions.

### EXAMPLES OF CLIMATIC LIMITATIONS.

Many alkali-resistant plants, such as cotton, rice, and the date palm, can be grown only in the warmer part of the country. Another case where climate plays an important part in deciding the choice of crop plants for alkali land is that of the Pacific Coast States, where the winter is mild and most of the rainfall occurs at that season. This allows certain crops to be grown on land containing too much alkali to permit success with the same crops in summer (see p. 8). The cereals—barley, wheat, etc.—often give good results under these conditions, especially when grown for hay. Various leguminous forage plants (for example, vetches and horse beans) can also be recommended as winter crops for moderately alkali land in the States mentioned. Similar results can doubtless be obtained in Arizona and adjacent regions of low rainfall, provided sufficient water is available for frequent irrigation in winter.

### FORAGE PLANTS USUALLY PREFERABLE.

It has been pointed out (p. 10) that many plants can tolerate a quantity of alkali which impairs the product for which they are grown to such a degree as to render them worthless as crops. On the



other hand, the majority of forage plants, being grown chiefly for their leaves and stems, are successful crops wherever the plants themselves can make a good growth. The meadow and pasture grasses, sorghums, common or foxtail millet, and rape are among the most satisfactory crops for land containing more than one-half of 1 per cent and less than 1 per cent of alkali, while such leguminous forage plants as alfalfa, vetches, Canada peas, and sweet clover may be expected to succeed in the presence of any quantity less than one-half of 1 per cent when a stand is once obtained.

#### RECLAMATION CROPS.

Such crop plants should be selected as can best endure the frequent floodings given alkali land that is being reclaimed. Sorghum is the most generally valuable crop for this purpose. Rice is extensively used in Egypt as a reclamation crop and can be recommended for localities in the United States which have a suitable climate and an ample water supply. When the reclamation is approaching completion it is the custom in Egypt to seed the land to the clover known as berseem, and if a good stand is obtained the soil is considered sufficiently free from salts for the growing of cotton, the principal crop of that country. As berseem succeeds well only as a winter crop in regions that are almost free from frost, its usefulness in the United States will necessarily be very restricted.<sup>1</sup>

The idea is current in some localities that alkali land can be reclaimed merely by growing certain resistant plants, such as salt-bushes and sugar beets. As a matter of fact, the plants mentioned when grown on alkali soils do take up considerable quantities of salts, as is shown by chemical analysis of their ash. The salts absorbed are, of course, removed from the land if the crop itself is removed. Yet the quantity of alkali taken out by the plants is usually so small in proportion to the total amount in the soil that it is very doubtful whether land containing any considerable quantity of salts could be permanently reclaimed by the removal of many successive crops.

#### GREEN-MANURE CROPS.

Alkali soils are apt to be deficient in humus, and, especially if any black alkali is present, they tend to become puddled when wet and to form a hard, baked surface when dry, offering much resistance to the penetration of water. The tilth of such land can often be improved by disking in barnyard manure or plowing under a green-

<sup>1</sup> For further information concerning crops grown in Egypt on alkali land that is being reclaimed, see Yearbook of the United States Department of Agriculture for 1902, pp. 573-588.



manure crop where such a crop can be grown.<sup>1</sup> The effect of thus incorporating organic matter is to loosen the surface, making it easier for water to penetrate the soil and to wash the salts downward. Furthermore, the loose material acts as a mulch, checking evaporation and hence retarding the return of the alkali to the surface. It is also probable that conditions more favorable to the accumulation of nitrogen can be established by increasing the supply of organic matter.

The crop plants suitable for green manure which are most likely to succeed where the alkali exceeds one-half of 1 per cent are sorghum, millet, barley, rye, rape, and kale. Where there is less than one-half of 1 per cent of alkali, certain leguminous plants—alfalfa, sweet clover, Canada peas, vetches, and horse beans—are likely to give good results if a stand can be secured. Where they can be grown, leguminous plants are preferable because they produce an immediate increase in the supply of nitrogen.

#### CROPS FOR ALKALI LAND NOT BEING RECLAIMED.

Others things being equal, those crop plants should be selected which leave the land in the best condition for succeeding crops. This depends upon the character of the plant itself and of the cultural methods used in growing it. Thus, alfalfa, if a stand can be obtained, will shade the ground more or less effectively at all times, reducing evaporation and thereby helping to prevent the salts from accumulating at the surface of the soil. On the other hand, the small grains (wheat, barley, oats, etc.) are less efficient in this respect and unless the stubble is disked or plowed up immediately after harvest and a soil mulch established, the intense evaporation from the hardened, unshaded surface will result in accumulating the alkali in the topsoil.

Intertilled crops, such as sugar beets and cotton, are desirable for land containing a moderate quantity of alkali, provided that a cultivation is given promptly after every rainfall or irrigation in order to check evaporation and thus prevent the return of the alkali to the surface. Even in the case of crops which are ordinarily seeded broadcast, it may be advantageous on alkali land to put in the seed with a drill, leaving enough space between the rows to permit cultivation.

On land containing too much alkali for crop production by ordinary methods, a stand can sometimes be obtained by planting the seed at the bottom of furrows and running water through the furrows at frequent intervals. This method has been successfully used

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<sup>1</sup>Methods for improving alkali land by the use of green-manure crops and of barnyard manure are described in United States Department of Agriculture Bulletin 135, entitled "Experiments in the Production of Crops on Alkali Land on the Huntley Reclamation Project, Montana," by Dan Hansen.



with sorghum in the Southwest. It has the effect of washing down what alkali is present at the bottoms of the furrows, but meanwhile the soil between them is subirrigated and the salts accumulate at the summits of the ridges. The same thing happens when orchards on alkali land are furrow-irrigated. The result in both cases is that ultimately the alkali condition of the topsoil is aggravated unless the land is occasionally leveled and heavily flooded in order to wash down the surface accumulation of salts.

#### CROPS FOR ALKALI LAND HAVING A HIGH WATER TABLE.

Shallow-rooted plants should be selected for alkali land having a high water table. In many cases the best use that can be made of such land is to convert it into permanent meadow or pasture, the grasses being shallow-rooted plants and also more or less tolerant of alkali. In addition to the native grasses which often occur naturally on such land, most of the cultivated grasses are well adapted to this purpose. As catch crops for land of this character when only a moderate quantity of alkali is present, the small grains (barley, rye, oats, and wheat) will give at least a hay crop, especially in years of heavy rainfall.

#### ALKALI RESISTANCE OF THE DIFFERENT CROP PLANTS.

In the following pages many of the crop plants grown in the Western States are discussed in connection with their behavior on alkali soils, the plants being arranged under the crop classes—forage plants, cereals, etc.—to which they belong instead of strictly in the order of their relative tolerance for alkali.

##### FORAGE PLANTS.

As a rule, forage plants are likely to give the most satisfactory results on alkali land, and among them hay and pasture plants which are grown principally for their stems and leaves are to be preferred to such plants as kafir, milo, and proso millet, in which seed production is an important feature.

In many parts of the West, barley, oats, and even wheat are extensively grown as hay crops, but to avoid repetition the relations of these plants to alkali will be discussed under the heading "Cereals."

##### MEADOW AND PASTURE GRASSES.

No class of cultivated plants can be more safely recommended for alkali land than certain meadow and pasture grasses. Subirrigated lands in valley bottoms that carry considerable salts can be utilized in no better way than as permanent grass meadows and pastures.



Western wheat-grass grows wild in many parts of the western United States, where it is highly esteemed for hay and pasturage.<sup>1</sup> It is frequently found occurring naturally in alkali land. In field experiments carried on by the writer it proved to be more tolerant of alkali than any of the other grasses tested. This plant can make some growth in the presence of 2 per cent of white alkali in the first 2 feet of the soil, and seed can be ripened in the presence of 1 per cent. Where the alkali is only medium strong (0.65 per cent) it has been found to make as good growth as in soil free from alkali.

Unfortunately, this grass is often a poor seed producer, since the heads are very often diseased with ergot. The percentage of germination of the seeds produced is also low, and the plants are very slow in starting growth, two or three years being required to get a full stand. Western wheat-grass should always be seeded in mixture with some of the other alkali-resistant grasses here mentioned.

Smooth brome-grass (*Bromus inermis*) and tall meadow oat-grass rank next to western wheat-grass in their tolerance of alkali. The growth of brome-grass is unhindered where the alkali is of the medium grade (0.5 per cent). In fact, this grass can make excellent growth and seed production where the alkali is medium strong (0.7 per cent), and it has been observed to ripen some seed in the presence of very strong alkali (1.5 per cent). Tall meadow oat-grass is apparently fully as tolerant as smooth brome-grass, being able to make a fair growth and ripen seed in the presence of strong alkali (1 per cent).

These three species—western wheat-grass, awnless brome-grass, and tall meadow oat-grass—can safely be recommended for land containing not more than 1 per cent of white alkali. Since the first two are rather slow-growing grasses, it will be advantageous to seed them in mixture with tall meadow oat-grass or with some of the species mentioned in the next paragraph.

Other grasses which have been tested and found to be adapted to alkali land, although somewhat less resistant than those just mentioned, are tall meadow fescue, Italian ray-grass or rye-grass, slender wheat-grass, redtop, orchard grass, and timothy, their tolerance for alkali being in about the order named, beginning with the most resistant. All of these species should give good results where the alkali is not more than of the medium grade, and most of them will usually succeed in the presence of medium-strong alkali if the salts are pretty evenly distributed throughout the depth of soil reached by the roots of the plants.

Italian ray-grass can be recommended as a lawn grass for moderately alkali land, although being rather short lived it has to be reseeded frequently.

<sup>1</sup> The high feeding value of western wheat-grass hay is shown by the results of analyses quoted in Bulletin 196, Bureau of Plant Industry, 1910, p. 30.



Bermuda grass is a useful pasture and lawn grass on irrigated lands of the Southwestern States and can withstand a moderate quantity of alkali. The recently introduced Rhodes grass (*Chloris gayana*) is also reported to have given promising results on alkali soils in southern Arizona and California.<sup>1</sup>

In seeding grasses on alkali land care should be taken to insure a seed bed relatively free from salt, either by planting immediately after heavy rains or by flooding before seeding. The small seeds of most of the species have little chance of success where there is a heavy accumulation of salts at the surface of the soil.<sup>2</sup>

Some of the native grasses of the western United States are among the most alkali resistant of plants. Western wheat-grass has already been discussed. The familiar salt-grass (*Distichlis*) is found in nearly all localities where alkali soils occur, and its presence is usually a reliable indicator that the soil contains at least a medium quantity of salts. It often covers the ground with a dense sod and affords considerable pasturage, although of a quality that is probably too inferior to warrant planting where this grass does not naturally occur.

#### SORGHUMS.

There is a general and well-founded belief in regions where alkali soils occur that the sorghums are among the best-adapted forage plants for this type of land. They lend themselves readily to culture on alkali land that is being reclaimed, since they can endure a great deal of flooding. It is the practice in some parts of the Southwest to seed sorghum at the bottoms of furrows, down which water is run at frequent intervals. This keeps the soil relatively fresh around the roots of the young plants and often permits a stand to be had in land containing too much alkali to produce a crop if ordinary methods of planting are followed.

The saccharine sorghums, being grown largely for their leaves and stalks, are likely to give more satisfactory results on alkali land than the milos and kafirs, in which seed production is more important. Amber sorghum can make a fair growth and develop heads in the presence of medium-strong white alkali, and a good crop may be expected in the presence of medium alkali provided other conditions

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<sup>1</sup> See Farmers' Bulletin 1048, entitled "Rhodes Grass," by S. M. Tracy.

<sup>2</sup> In Bulletin 168 of the Utah Experiment Station, entitled "Relative Resistance of Various Crops to Alkali," by F. S. Harris and D. W. Pittman, the standard meadow grasses are rated low in comparative alkali resistance during the seedling stage of growth. These investigators drew their conclusions from the results obtained with pot cultures, in which, presumably, a uniform concentration of alkali was maintained throughout the soil mass. On the other hand, the conclusions stated in the present bulletin are based upon field experiments, in which the seeding was done as soon as possible after a rain or a heavy irrigation, thus allowing the small grass seeds to germinate and the delicate seedlings to become established before much of the alkali had returned to the surface soil.



are favorable. In the germinating and seedling stage the plants do almost as well in the presence of medium-white alkali as in soil practically free from these salts. In fact, no other crop plant with which the writer has experimented has shown so great a degree of resistance in this stage of growth. Sorghum is also apparently more resistant to black alkali than are the majority of crop plants.

#### MILLETS.

Common or foxtail millet is an excellent crop for moderately alkali land. A good crop may be expected where there is not more than a medium quantity of white alkali. The germination of the seeds and the growth of the plants during the seedling stage are not materially hindered by this quantity of salts if there is not too great an accumulation at the surface of the soil. In the presence of medium-strong alkali a fair crop can be produced, and a limited growth and seed production are possible under otherwise favorable conditions even where strong alkali occurs. One per cent of white-alkali salts in the depth of soil occupied by the roots is probably the extreme limit for seed production, and this quantity is too great for profitable crop production.

The proso or broom-corn millets are also decidedly tolerant of alkali, but as they are grown mainly for their seed it is doubtful whether they are as suitable a crop for such soils as the foxtail millets. The yield of straw on alkali land also appears to be lighter in the case of the prosos. The results of the writer's experiments in the field indicate that the upper limit of the weak grade of white alkali (0.4 per cent) is about the limit for a good crop of proso. Growth and seed production were greatly reduced at the upper limit of the medium grade (0.6 per cent).

#### RAPE AND KALE.

Rape and kale, which are extensively used for forage in Europe but are little grown in the western United States, are decidedly tolerant of salts. Essex rape makes a fair growth in the presence of medium-strong white alkali. Where the alkali does not exceed the upper limit of the weak grade (0.4 per cent), the plants can reach full size. Forage kale (the Thousand-Headed variety) appears to be at least equally resistant, making a fair growth in the presence of medium-strong white alkali.

The chief objection to these plants as a crop for alkali land is the difficulty frequently experienced in getting a stand. They appear to be decidedly more sensitive than the sorghums and millets while in the germinating and seedling stages. The small and delicate seedlings also have great difficulty in breaking through the crust that forms on the surface of certain types of alkali land when allowed to become



too dry. Care should therefore be taken in seeding these crops on such land to first wash the salt out of the surface soil and to irrigate frequently enough to prevent a hard crust forming until the plants are sufficiently large to shade the ground. With these precautions to insure a stand, rape and kale are likely to prove useful as green-manure crops for alkali soils, which are often deficient in humus.

#### SALTBUSHES.

The saltbushes (species of *Atriplex*)<sup>1</sup> are among the most characteristic of the native plants of the western United States which grow naturally on alkali land. In fact, the presence of many of the species is a reliable indicator that the soil contains salts in sufficient quantity to injure the majority of cultivated plants. Saltbushes are of more or less value as an element of the natural pasturage or range of the western United States, being browsed by cattle and sheep, especially when grass is scarce. While it has been demonstrated that the North American species can be successfully seeded on moist alkali land,<sup>2</sup> it has not been proved that the enterprise would be a profitable one. Some of the Australian saltbushes were rather extensively tested a few years ago by the California Agricultural Experiment Station, and were found capable of tolerating an excessive quantity of alkali, in one case as much as 4 per cent in the first 4 feet of the soil. But it has not been demonstrated that the value of the crop will warrant the expense of getting a stand, and the saltbushes have not been taken up by farmers to any important extent. The Australian species will probably succeed only in regions having a mild winter, like California, Arizona, and possibly southern Nevada and parts of New Mexico and Texas.

The value of some of the larger-growing saltbushes for making hedges and windbreaks in alkali land is discussed on another page.

#### LEGUMINOUS FORAGE PLANTS.

Plants of the pea family (Leguminosæ) are generally sensitive to alkali, as is indicated by the fact that very few species of this large and widely distributed family grow naturally in salty soils. Nevertheless, some of these plants are fairly tolerant and can be grown in land carrying a moderate quantity of salts—provided the conditions are otherwise favorable. Unless the topsoil is practically free from alkali at the time of seeding, a greater measure of success is likely to be had with large-seeded species, such as field peas, vetches, and horse

<sup>1</sup> The North American and Australian saltbushes are discussed by J. G. Smith in the Yearbook of the United States Department of Agriculture for 1898, pp. 535 to 550, with special reference to their utility on alkali land, and by P. B. Kennedy, in Farmers' Bulletin 108, 1900, entitled "Saltbushes." See also United States Department of Agriculture Bulletin 617, entitled "Australian Saltbush," by Roland McKee.

<sup>2</sup> In Bulletin 63, Wyoming Agricultural Experiment Station, 1904, methods of planting are described on page 17.



beans, than with small seeds like those of alfalfa and clover. The Leguminosæ are very sensitive to sodium carbonate, and their culture should not be attempted if black alkali is present in appreciable quantity. Where the soil contains not more than a medium quantity of white alkali, alfalfa, berseem (Egyptian clover), sweet clover, Canada field peas, horse beans, and some of the vetches may be grown with fair success. Where these plants can be grown they will be found beneficial to alkali soils if plowed in, since the material thus added not only improves the tilth and increases the supply of humus, which such soils often lack, but also furnishes nitrogen for the use of succeeding crops.

**Alfalfa.**—Being the most extensively grown forage crop of the western United States, alfalfa has received more attention than any other leguminous plant with respect to its relations to alkali soil.

It is difficult to start in even moderately alkali land in case the salts are largely accumulated in the surface soil, but if seeded just after a heavy rain or irrigation the taproots of the young plants will speedily penetrate to a considerable depth and by the time evaporation has brought the salts back to the surface the feeding roots may be largely out of reach of the surface accumulations. It is a common experience in the West to see old plants of alfalfa growing vigorously in the presence of surface accumulations of salts that would absolutely prevent getting a stand. In such cases the greater part of the alkali must have risen after the alfalfa was seeded. If a stand can be obtained alfalfa is well adapted to preventing excessive accumulation of salts in the topsoil, owing to the shade constantly afforded by this crop. It has been observed that alfalfa can flourish for years in land where, if the stand is plowed up, the salts quickly accumulate near the surface in such large quantity that grain can not be successfully seeded.

In the germinating and seedling stage alfalfa has given satisfactory results where the alkali in the first 6 inches of the soil was at the lower limit of the medium grade (0.4 per cent), with no black alkali present. Young alfalfa is exceedingly sensitive to black alkali, but Prof. Hilgard states that if only a slight amount of sodium carbonate is present a stand can sometimes be obtained if gypsum or land plaster is sown with the seed.

Alfalfa when once established can endure the upper limit of the medium grade of white alkali (0.6 per cent) if the salts are mostly sulphates. If chlorids form a large proportion of the alkali the lower limit of this grade (0.4 per cent) is usually about the limit for a healthy growth. But where the soil is very sandy as little as 0.2 per cent of the chlorid type of alkali may injure the plants, the soil solution being more concentrated in a sandy than in a loam or clay-loam soil.



The percentages mentioned represent the average limits for the profitable production of alfalfa in the presence of different types of alkali. Occasional individual plants are more resistant and have been observed to ripen seed in the presence of as much as 1 per cent where the alkali was largely common salt (sodium chlorid).

**Field peas.**—Next to alfalfa the Canada field pea is the most important leguminous forage crop grown in the western United States. In the germinating and seedling stages the upper limit of the weak grade of alkali (0.4 per cent) marks about the limit of tolerance for this plant. Where white alkali of the sulphate type does not exceed 0.2 per cent of the weight of the soil, germination has been observed to take place as readily as in soil free from alkali. Crop production is possible in the presence of a medium quantity of sulphate alkali (0.5 per cent), and a good crop can be obtained where the alkali does not exceed the lower limit of this grade (0.4 per cent).

**Sweet clover.**—The white-flowered sweet clover is a common weed in many irrigated districts and often attracts attention because of its luxuriant growth under apparently unfavorable conditions. It is usually avoided by stock on account of the bitter and aromatic flavor of the plant, although it is stated that horses, cattle, and sheep can become accustomed to it and even learn to relish it. Sweet clover is a very efficient nitrogen gatherer and undoubtedly possesses considerable value as a green-manure crop. It is generally believed that this plant is much more tolerant of alkali than is alfalfa, but the results of experiments in alkali soils have indicated that medium alkali (0.5 per cent) is about the limit for good germination and the production of a heavy crop of sweet clover. Where this percentage of alkali is present in the surface soil it is probably easier to get a stand of sweet clover than of alfalfa. In land having a high water table sweet clover can be successfully grown where alfalfa will not thrive.<sup>1</sup>

The yellow-flowered sweet clover, or "sour clover," is much more common in the Southwest than the white-flowered species. In Arizona, where it makes most of its growth in winter, this plant is likely to prove useful as a green-manure crop for alkali land of the medium and weak grades.

**True clovers.**—Little is known about the alkali resistance of the clovers ordinarily grown in the United States—red, white, crimson, and alsike. It is probable that all of these species are rather sensitive.

Berseem, or Egyptian clover, is extensively grown in Egypt as a winter crop on alkali land under reclamation and is used there as an indicator of the degree to which the salts have been washed out of

<sup>1</sup> The alkali resistance of sweet clover is discussed in Farmers' Bulletin 797, entitled "Sweet Clover: Growing the Crop," by H. S. Coe, pp. 13, 14.



the soil. As soon as a stand of clover can be had it is considered safe to put the land into cotton. Berseem is particularly useful as a reclamation crop because it can endure a great deal of moisture and is not injured by the frequent floodings given land that is being reclaimed. The medium grade of alkali, where sodium chlorid is the principal salt, is believed in Egypt to be about the limit for the successful growth of this clover. Attempts to utilize this plant in the United States have not been very successful. As it is sensitive to frost and apparently also to hot weather its usefulness will be restricted to localities having a very mild winter.

**Vetches.**—Two species of vetch, the hairy vetch and the scarlet vetch, have been rather thoroughly tested and have proved easier to germinate in alkali soils than any other leguminous plants included in the writer's experiments. Hairy vetch gives a good germination and produces a fair hay crop where alkali of the sulphate type does not exceed the lower limit of the medium grade. Scarlet vetch appears to be at least equally resistant, making a heavy crop in the presence of the medium grade of sulphate alkali. The lower limit of this grade (0.4 per cent) does not appreciably retard the germination and seedling growth of scarlet vetch, and as much as 1 per cent does not prevent germination, although the seedlings grow very slowly at this concentration. It is unlikely that profitable crops can be grown if the alkali exceeds the upper limit of the medium grade (0.6 per cent).

**Horse bean.**—The horse bean is extensively grown in the Old World as a forage plant. A large-seeded form (the so-called "broad bean") is a favorite table vegetable in Europe. In the United States the plant has been grown only experimentally and appears to succeed best as a winter crop in California and as a summer crop in rather elevated regions, such as eastern Wyoming, where the summer is comparatively cool. It appears to be decidedly more tolerant of alkali than the majority of leguminous plants. The large size of the seeds makes it easier to get a stand in alkali land than is the case with most plants of this family. As it produces a considerable quantity of vegetable matter, the horse bean is worthy of consideration as a green-manure crop for alkali land in localities having a suitable climate. Hot weather soon puts an end to the growth of the plants and causes them to turn black. In soils where the alkali is of the sulphate type the young plants will tolerate medium-strong alkali. Numerous pods are set where the alkali does not exceed the lower limit of the medium grade (0.4 per cent).

#### SUGAR BEETS.

Sugar beets are undoubtedly the most alkali resistant of the important field crops grown in the western United States. But while the plants can tolerate excessive quantities of salts, it is not profitable



to grow them in very strong alkali soils because of the injurious effect of the alkali upon the size of the roots and the purity coefficient of the juice. The actual limits for profitable beet growing must be ascertained in each locality by testing the effect of the prevailing type of alkali upon the composition of the roots.

As a rule, a good stand of sugar beets can not be expected if the soil around the germinating seeds and the roots of the young seedlings contains more than the medium grade of white alkali (about 0.5 per cent). One-tenth of this amount of black alkali (sodium carbonate) is probably the greatest quantity which will permit a stand being obtained. Experienced beet growers find that a heavy irrigation previous to planting often makes it possible to secure a stand in alkali land where without this precaution beets could not be successfully started. The subsequent return of the salts to the surface of the soil may not injure the plants, since after the seedling stage is past sugar beets are much more tolerant of alkali.

When once established, sugar beets can be expected to produce a good crop of marketable roots where white alkali (sulphates, chlorids, and bicarbonates) occurs in a quantity not exceeding the medium grade. Even where the alkali is medium strong or strong, a crop of beets suitable for sugar manufacture can sometimes be made if favorable moisture conditions are maintained and the soil is not too sandy. A much smaller quantity of black alkali will prevent a crop, although sugar beets will apparently endure more sodium carbonate than will the great majority of crop plants.

The fact that the beet is a cultivated crop recommends it for growing on alkali land, since intertillage is one of the most effective methods of keeping the salts from accumulating at the surface of the soil, provided the field is cultivated as soon as possible after every rainfall or irrigation.

#### CEREALS.

The small grains (wheat, emmer, barley, oats, and rye) can not be recommended for land containing more than weak alkali except when grown as a hay crop (see p. 14). While the plants can grow in the presence of a considerable quantity of salts, the quality of the grain is likely to be inferior, the kernels being small and more or less shriveled. Furthermore, unless the land is plowed immediately after harvest an accumulation of salts at the surface of the soil is favored, since grain stubble affords little or no protection against evaporation and the baking of the soil surface. The land is thus rendered less fit for succeeding crops. Corn is decidedly sensitive and should not be grown on alkali land. Rice, being able to endure a great deal of flooding, may be used as a reclamation crop in regions having a suitable climate.



Wheat for milling purposes should not be grown in land containing more than weak white alkali. A good hay crop with a fair yield of grain can be obtained in medium white alkali if the soil is a loam or clay loam and the moisture conditions are favorable. If black alkali is present, the limits will, of course, be very much lower.

Emmer appears to have about the same degree of alkali resistance as wheat.

Barley is more tolerant of alkali. The crop can be grown in medium white-alkali land, although near the upper limit of this grade it is unlikely that a high quality of grain can be obtained. In loam or clay-loam soils, if a favorable moisture content is maintained, barley can be grown as a hay crop even when the alkali reaches the medium-strong grade, provided the alkali content of the topsoil at the time of seeding does not exceed the medium grade. The limits in the presence of black alkali are much lower, although barley appears to be decidedly superior to wheat in tolerance of sodium carbonate.

For oats, under ordinary conditions, the medium grade of white alkali is about the limit for a profitable hay crop and a fair yield of grain. A full crop and high quality of grain can not be expected if the alkali exceeds the upper limit of the weak grade unless other conditions are exceptionally favorable.

Rye is almost, if not quite, equal to barley in tolerance of alkali. A fair crop of grain can be obtained in the presence of the medium grade of white alkali. Rye is well adapted for growing as a green-manure crop on alkali land, although a good stand can not be expected if the topsoil at the time of seeding contains more than medium alkali.

Corn is decidedly more sensitive than the small grains and is not to be recommended for alkali soils. In Egypt, where extensive areas of alkali land occur and where the people have long been familiar with this problem, corn is said to fail on land that will produce good crops of rice and cotton. Experiments in the United States indicate that even where the alkali is only of the weak grade a good crop of corn can not be expected.

Rice is regarded as sensitive to brackish water in Louisiana and Texas, but in Egypt it is one of the principal crops grown on alkali land that is being reclaimed by drainage and flooding. A good crop has been observed in that country where the alkali in the soil (mainly sodium chlorid) was of the strong grade (1 per cent). It does not follow that the rice plant is actually much more resistant than other cereals, for the frequent flooding of land under reclamation keeps the soil solution relatively dilute provided the irrigation water itself has a low salt content. In a publication of the Texas Agricul-



tural Experiment Station<sup>1</sup> it is stated that the irrigation of rice with water containing 0.3 per cent of sodium chlorid is likely to injure the crop and that water containing as much as 0.5 per cent should never be used.

#### FIBER PLANTS.

##### COTTON.

Cotton has recently become an important crop under irrigation in the Southwest. The plants are decidedly tolerant of alkali, making a fair growth in the presence of very strong alkali where sodium chlorid is the principal salt. But the limits for a profitable crop are much lower, since it has been observed that a quantity of alkali that is too small to appreciably hinder the growth of the plants has an injurious effect upon the number and size of the bolls and retards their ripening, besides impairing the length and fineness of the fiber. So far as can be judged from present information it is inadvisable to grow Egyptian and other superior types of cotton where chlorid alkali of more than the weak grade occurs. Profitable crops of short-staple Upland varieties, in which the quality of the fiber is less important, may very likely be produced in the presence of medium alkali of this character.

Cotton, being intertilled while the plants are young and shading the ground very effectively after the middle of the summer, is a desirable crop for moderately alkali land in the southern part of the arid region. It requires less irrigation, especially during the early stages of growth, than most of the summer crops which are grown in that region. It is all the more important, therefore, that thorough cultivation be given in order to prevent the accumulation of the salts at the surface of the soil.

##### FLAX.

Flax has been observed in unirrigated land of North Dakota to make a fair crop where the surface foot of the soil contained sulphate alkali of the medium grade, and a good crop at the lower limit of this grade (0.4 per cent). The presence of an excessive quantity of salts in the soil below the first foot had apparently no injurious effect.

#### GARDEN VEGETABLES AND TRUCK CROPS.

Only scanty data are available for forming a conclusion as to what garden vegetables are most tolerant of alkali. It is decidedly inadvisable in the present state of knowledge to grow any truck crop on a large scale in alkali soil. The following suggestions are intended

<sup>1</sup> Fraps, G. S. The effect of salt water on rice. Bulletin 122, Texas Agricultural Experiment Station, 1909.



for the farmer whose land contains more or less salts and who desires to grow vegetables in a small way for home use.

Asparagus is generally given the first rank among garden vegetables in tolerance of alkali and when grown in eastern soils appears to be actually benefited by application of common salt (sodium chlorid). White alkali of the medium grade does not prevent the successful growing of asparagus. Onions are also reported to be adapted to white-alkali land of the medium grade. Celery is said to do well in California in the presence of the weak grade of alkali where sodium chlorid is the principal salt.

Other truck crops which are worthy of trial on alkali land of the medium and weak grades, although little is known about their actual degree of resistance, are the globe artichoke, the beet, cabbage, cauliflower, celery, eggplant, kale, spinach, sweet potato, and watermelon.

Irish potato plants make a fair growth in the presence of white alkali of the medium grade, but the tubers produced are too small to be marketable. Where the alkali is near the lower limit of the weak grade, potatoes of good quality can doubtless be produced.

#### TREES AND SHRUBS.

It is extremely difficult to determine the limits of the alkali resistance of trees, since, in addition to the quantity and kind of salts, the depth of soil in which the alkali is located must be considered in connection with the different kinds of root systems possessed by the different species of trees. A high-water table, which is often associated with the presence of alkali, is very injurious to most woody plants.

#### FRUIT TREES AND GRAPES.

In addition to the matters already mentioned, the effect of the salts upon the keeping quality and flavor of the fruit can not be overlooked in the case of orchard crops. It can only be said in a general way that strong alkali soils should be avoided in planting fruit trees, except the date palm and the pomegranate, which will tolerate considerable quantities of salts. The pear and the fig are also fairly resistant so far as concerns the growth of the trees, but the quality of the fruit suffers if more than a very limited quantity of alkali is present.

The various stone fruits (plum, peach, apricot, cherry, etc.) are considered sensitive to alkali. The same is true of the orange, lemon, and other citrus fruits and of the English walnut.

Grapes of the European class (*Vitis vinifera*) may be expected to ripen fruit of good quality, except for raisin making, wherever the quantity of alkali present is not sufficient to injure the vines themselves.



## ORNAMENTAL AND SHADE TREES.

The cottonwoods, so extensively planted along roads and ditches and about houses in the western United States, appear to be fairly tolerant of alkali. *Populus fremonti* is said to be the species best adapted to such land. The black locust, honey locust, and Russian mulberry are also reported to be suitable for planting on soil containing only a moderate quantity of alkali. In portions of the Southwest having a mild winter the list of trees that are likely to succeed in such land can be extended to include the umbrella or china-berry tree (*Melia azedarach*), the Japanese varnish tree (*Koelreuteria*), the European plane tree (*Platanus orientalis*), the oleander, the Australian beefwoods (species of *Casuarina*), the Washingtonia palm, and the date palm. The Canary Island palm (*Phoenix canariensis*), a near relative of the date palm, is also probably tolerant of alkali. Of the species of eucalyptus which have been tested in California, the desert gum (*Eucalyptus rudis*) and the red gum (*Eucalyptus rostrata*) appear to be best adapted to alkali soils.<sup>1</sup>

## HEDGES AND WINDBREAKS.

Of the shrubs and small trees suitable for hedges and windbreaks the Russian olive is one of the species that can best endure the presence of a moderate quantity of salts. Golden willow is also probably worth testing in regions having a severe winter. In the Southwest the pomegranate and tamarisk (*Tamarix gallica*), both of which are decidedly alkali resistant, are excellent hedge plants. The latter is hardly as far north as central-western Nevada. Some of the larger growing saltbushes are very tolerant of alkali and make good hedges. *Atriplex breweri* is already in use as a hedge plant in the coast region of California and *Atriplex lentiformis* is recommended for the purpose in Arizona.<sup>2</sup>

## CONCLUSIONS.

The principal conclusions reached in regard to the adaptability of different crop plants to alkali soils and the choice of crops for land of this character may be summed up as follows:

(1) All useful plants are extremely sensitive to black alkali, and the conclusions stated in the following paragraphs do not apply in case an appreciable quantity of sodium carbonate is present.

(2) Practically none of the important field crop plants can be profitably grown where the quantity of white-alkali salts (sulphates,

<sup>1</sup> See Bulletin 225, California Experiment Station, entitled "Tolerance of Eucalyptus for Alkali," by R. H. Loughbridge.

<sup>2</sup> See Griffiths, David, "The Ornamental Value of the Saltbushes," Circular 69, Bureau of Plant Industry, 1910.



bicarbonates, and chlorids) in the depth occupied by the roots exceeds 1 per cent of the dry weight of the soil. Only a few decidedly resistant species can be expected to give good crops where the quantity exceeds one-half of 1 per cent.

(3) Forage plants, especially such as are grown chiefly for hay and pasturage rather than for seed production, are usually to be preferred for growing in alkali land.

(4) Many of the standard meadow and pasture grasses can be successfully grown where the quantity of alkali within reach of the plant roots forms from one-half of 1 per cent to 1 per cent (0.5 to 1 per cent) of the dry weight of the soil. But a good stand of these small-seeded plants can be obtained only if most of the alkali has been leached out of the surface soil at the time of seeding. This may be accomplished by flooding, or the seeding may be done immediately after heavy rains.

(5) Subirrigated alkali land having a high water table can be utilized by seeding to meadow and pasture grasses, most of which have shallow roots.

(6) Foxtail millet, rape, kale, and sorgo, as well as barley and rye, when grown for hay, will often give fair yields if the quantity of alkali does not exceed the upper limit of the medium-strong grade (0.8 per cent).

(7) Certain leguminous forage plants, notably sweet clover, alfalfa, Canada field peas, and vetches, should give a fair yield where the alkali is not above the medium grade (about 0.5 per cent). Success with these crops depends largely upon planting at a time when the surface soil is relatively free from salt.

(8) Alkali soils which have a tendency to puddle and form a hard crust on the surface can be improved by plowing under green-manure crops where any such crop can be grown. This practice loosens the soil, facilitating the penetration of water and hence the leaching out of the salts. Good crops for this purpose are sorgo, millet, barley, rye, rape, and kale, where the alkali is medium strong or medium; and vetches, Canada field peas, horse beans, and sweet clover, where the alkali is weak.

(9) For alkali land that is being reclaimed by flooding, sorgo is probably the most satisfactory catch crop that can be grown during the progress of the work. In regions where the climate is suitable for its culture, rice is a good crop for this purpose, and the same is true of berseem (Egyptian clover) in localities having a mild winter. All of these crops can endure frequent and heavy applications of water.

(10) The sugar beet is the most resistant of the important crop plants of the western United States, but the quality of the roots for



sugar manufacture is impaired by a quantity of alkali that does not hinder the growth of the plants. In the presence of the medium grade of white alkali a profitable crop of beets may usually be expected, and if other conditions are exceptionally favorable as much as 1 per cent of salts can be tolerated. One-half of 1 per cent in the surface soil at the time of seeding is about the limit for getting a stand. Beets, being an intertilled crop, are well adapted for preventing an accumulation of salts at the surface of the soil, provided a cultivation is given as soon as possible after every rainfall and irrigation.

(11) Of the cereals, barley, rye, oats, wheat, and emmer are fairly tolerant of alkali so far as the plants are concerned, but the presence of more than the weak grade usually prevents the production of well-filled heads and plump grain. If grown in alkali land the stubble should be disked or plowed in immediately after harvest in order to prevent the baking of the ground and the consequent accumulation of salts at the surface. Barley and rye are somewhat more resistant than the other species and may be expected to give a hay crop in the presence of medium alkali and sometimes even of medium-strong alkali. Corn is much more sensitive than the small grains and should not be planted on alkali land.

(12) Cotton is decidedly resistant so far as the growth of the plants is concerned, but good yields of fiber can not be expected where the alkali exceeds the medium grade. Egyptian and other long-staple types in which a high grade of fiber is required should not be grown in the presence of more than weak alkali.

(13) None of the truck crops and garden vegetables can at present be recommended for extensive planting on alkali land. Where it is desired to grow vegetables in a small way for home use, asparagus, onions, celery, beets, spinach, cabbage, cauliflower, kale, eggplant, tomatoes, sweet potatoes, and watermelons may be tested. Of these, asparagus and onions are the most likely to succeed on land containing as much as the medium grade of alkali.

(14) Of fruit trees, only the date palm and pomegranate do well on strong alkali land. If the total salts present do not exceed the lower limit of the medium grade (0.4 per cent), pears, figs, and grapes of the European type (*Vinifera*) are likely to thrive and bear fruit of fair quality.

(15) The following shade and ornamental trees are reported to be successful in moderately alkali land: Cottonwood, black locust, honey locust, and Russian mulberry. Of trees adapted only to regions having a mild winter the date palm and *Washingtonia* palm can tolerate considerable alkali, and the umbrella tree, European



plane tree, Japanese varnish tree, and some species of eucalyptus are also said to be fairly resistant.

(16) Of shrubs suitable for hedges and windbreaks in alkali land, Russian olive and possibly golden willow, in districts having a severe winter, and tamarisk, pomegranate, and the large-growing salt-bushes, in milder regions, are the most likely to give satisfactory results.

